Glutenin Macropolymer in Salted and Alkaline Noodle Doughs

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ABSTRACT

An attempt was made to understand the physicochemical attributes that are the basis of physical differences between alkaline and salted noodle doughs. Flour and dough properties of one soft and three hard-grained wheat cultivars were observed. Doughs were made with either sodium chloride or sodium carbonate. Each formulation variant was tested at both high and low water additions. Samples for glutenin macropolymer (GMP) isolation were taken at selected noodle dough processing stages. When a 1.67% w/v Na_2CO_3 solution was used for mixograph testing, dough characteristics were radically altered and differences between cultivars were masked. In lubricated squeezing flow (LSF) testing, hard wheat noodle doughs had significantly ($P < 0.01$) longer relaxation times and higher % residual force values than soft wheat doughs in both the salted and alkaline variants. LSF maximum force and biaxial viscosity were significantly higher in alkaline doughs than salted. GMP extracted from alkaline doughs was gummy and sticky, and was more opaque than GMP from salted doughs. GMP weight decreased sequentially when extracted from samples taken in the active phase (mix, compound, sheet) of noodle dough processing and decreased more in alkaline doughs. GMP weight increased more after 24 hr of dough rest in salted doughs. GMP gel strength was noticeably higher in GMP extracted from alkaline doughs. After dough resting, alkaline GMP gel strength significantly increased, whereas it decreased in GMP from salted doughs, suggesting a role for GMP in the increased stiffness of alkaline noodle doughs.

There are differences between alkaline and salted noodles that include differences in their dough properties. However, little if anything is known regarding the underlying physicochemical processes that are associated with the differences in dough properties, which have been reported in a number of studies. Moss et al (1986) reported increased resistance to extension and reduced extensibility in conventional alkaline-carbonate doughs when compared to conventional flour and water doughs. (hereafter conventional will refer to doughs with water additions appropriate for breadmaking: 50–70% flour basis). Chu (2004) also reported increases in farinograph development time and stability, and extensigraph maximum resistance on the addition of carbonates to conventional dough formulations. More recently, Ross and Ohm (2006) using a lubricated squeezing flow (LSF) technique (Ross and Ohm 2006; Liao et al 2007) reported that alkaline-carbonate noodle doughs were harder in consistency, more elastic, and had higher biaxial viscosities than salted doughs made from the same flour. There also appear to be differences related to both flour composition and alkali type. One study observed that doughs had increased LSF relaxation times and biaxial viscosities when doughs were made with Na_2CO_3 compared to doughs made with salt. But doughs made with a low protein flour had greater proportional increases in these parameters than a high protein flour (Ross and Ohm 2006). Wu et al (2006) examined noodle doughs made from high and low protein flours using dynamic rheometry. These workers observed a greater increase in dynamic storage modulus in noodle doughs made from the low protein flour when made with a 9:1 mixture of Na_2CO_3 to K_2CO_3 (kansui) at additions of 0.5 and 1.0% fwb. However, the high protein flour had greater increases in dough G' when noodle doughs were made with 0.5 and 1.0% fwb NaOH. Finally, there is the possibility that the ratio of Na to K in kansui has an effect. However, Hatcher and Anderson (2007) showed that varying the Na to K ratio in alkaline-carbonate formulations, in the absence of NaCl, had little if any systematic effect on the work required to sheet noodle doughs, suggesting at the most only a minor role for the Na_2CO_3 to K_2CO_3 ratio.

Our original hypothesis was that alkali treatment influences the gluten proteins directly, given the primacy of gluten in determining dough properties. Accordingly, we considered it appropriate to examine the flour and dough proteins as a first gambit in our investigation. In particular, we were interested in observing the behavior of glutenin macropolymer (GMP) during noodle dough processing as a result of reports showing different responses of GMP properties to conventional mixing (Don et al 2003a) and to mixing in simple shear (Peighambardoust et al 2005). Noodle dough processing appears to be somewhat intermediate and arguably contains elements of both mixing procedures; noodle doughs are first mixed rotationally and then have planar extension applied in the sheeting process. GMP was also considered important because it would be related to measurable noodle dough properties, as it has been related to conventional dough properties. It is generally agreed that GMP forms the elastic component of the gluten complex in conventional wheat flour doughs. There are competing hypotheses regarding the molecular and colloidal level mechanisms that are responsible for glutenin elasticity in these circumstances. These were reviewed recently (Hamer et al 2009) and are not discussed further here. GMP is made up mainly of insoluble high and low molecular weight glutenin subunits (HMW-GS and LMW-GS, respectively) (Lindsay and Skerritt 1999, 2000). In conventional doughs, the quantity, rheology, and structural characteristics of GMP appear to be predictive of dough properties and bread loaf volumes (Don et al 2003a,b; 2005) In turn, the rheological and structural characteristics of GMP may be linked to the HMW-GS composition of the source flour (Don et al 2006). Relations between GMP quantity and rheology and the behaviors of noodle doughs and the quality of the cooked noodles may differ from relationships observed between GMP characteristics and breadmaking doughs and their resultant breads. These potential differences are likely to arise as a result of all or some of the formulation and processing differences occurring in noodle doughs. However, there are no reports in the literature regarding GMP in relation to noodle doughs. The specific aims of this study were to make observations of dough characteristics and the properties of GMP during processing of both salted and alkaline-carbonate noodle doughs using a selected set of flour samples that varied in conventional dough attributes and flour protein concentration.

MATERIALS AND METHODS

Grain from four winter wheat cultivars was harvested at various locations in the United States Pacific Northwest region in 2005. The cultivars were soft white winter (Stephens); and hard red

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winter (Rampart, Carter [submitted as BZ9W02-2060], and Bynum [submitted as MTCL0318]). Straight-grade flour samples were obtained through the generosity of the participants in the Wheat Quality Council of the United States Pacific Northwest. Grain was milled into flour using a Miag Multomat pilot-scale flour mill at the USDA-ARS Western Wheat Quality Laboratory (WWQL) as previously described (Martin et al 2007). Analytical data on the flours was contributed by the WWQL. Moisture, ash, and protein contents, and constant flour weight farinograph parameters were determined using Approved Methods 44-15A, 08-01, 46-30, and 54-21, respectively (AACC International 2000). Protein content % was calculated as N × 5.70 and reported on a 14% flour moisture basis. All WWQL analyses used to characterize the samples were determined as single determinations. Table I shows these previously determined characteristics of the four flour samples. All chemicals used were analytical grade or better.

Mixograph dough properties were evaluated using Approved Method 54-40 (AACC International 2000) but with the additional use of either a 2% w/v aqueous solution of NaCl or a 1.67% w/v solution of anhydrous Na_2CO_3. When saline and alkaline solution additions were 60% fwb, the amounts of NaCl and Na_2CO_3 provided the same w/w solids concentrations on a flour basis as used in noodle dough formulations in this study (NaCl: 1.2 g/100 g of flour; Na_2CO_3: 1.0 g/100 g of flour). Small variations in salt or alkali amounts as a result of mixograph absorptions ±60% were not considered to be of practical significance.

Salted noodle doughs were manufactured according to Ohm et al (2006) with modifications. Doughs were made at a constant water addition of 32% so that differences in dough properties related to differences in water absorption capacity between treatments might be observed. Alkaline noodle doughs were made using the same method but modified to use 1% fwb of anhydrous Na_2CO_3 in place of 1.2% fwb NaCl. Noodle processing was divided into four stages: 1) mixing, compounding (4 mm roll gap), sheeting (successive passes through 3.5, 3.0, 2.0, and 1.5 mm roll gaps), and resting. Mixing, compounding, and sheeting, as a group, are referred to in the narrative as the active phase of processing. After each processing stage, 10 ± 0.5 g of dough was removed and immediately frozen with liquid nitrogen. Frozen samples were stored at –80°C until required for GMP extraction. Constant area, constant velocity LSF rheology incorporating a stress relaxation step was conducted on sheeted noodle doughs using a texture meter (TATXplus, Texture Technologies, Scarsdale, NY) following the method of Ross and Ohm (2006) with modification. Immediately after the dough was sheeted through the 1.5 mm roll gap, a subsample of the sheet was taken and four circular dough pieces were cut from it using a 25.4 mm i.d. punch (#149, C.S. Osborne and Co., Harrison NJ). Two of the circular dough pieces were immediately subjected to LSF testing (0 hr, unrested). The two other dough circles were stored at room temperature for 24 hr in zip-closure bags before they too were tested using LSF (24 hr, rested). All dough specimens were subjected to uniaxial compression to 90% strain leading to biaxial flow of the dough pieces. After reaching 90% strain, doughs were held there for a further 30 sec and the stress relaxation was observed. Parameters measured were dough thickness, maximum stress to compress to 90% strain, residual force after 25 sec at 90% strain, residual force as a proportion of maximum force (% RF), and relaxation time (time for stress to decline to 1/e of the maximum value). Raw force and distance data were converted to stress, strain, strain rate, and apparent biaxial extensional viscosity (ABEV) using equations described by Ross and Ohm (2006) and Baltsavias et al (1999).

For GMP isolation, flour and freeze-dried noodle doughs were defatted using the procedure described by Peighambardoust et al (2005). GMP was isolated from the defatted material using the method described by Don et al (2003a) with the modification that a 2.2% w/v solution of SDS was used. The GMP wet weight was recorded and a 1 ± 0.05 g sample of the GMP gel was used immediately for rheological testing using the method of Don et al (2003a) with modification. The GMP sample was transferred onto the measuring cell of the rheometer (Bohlin VOR, Malvern Instruments, Worcestershire, UK). The measuring cell consisted of 25 mm diameter parallel plates with a gap size of 1 mm. Excess gel sample was scraped from the sides of the plate and silicone oil was applied to prevent drying. Strain sweep measurements were performed at room temperature at amplitudes of 1–100% at 0.15 Hz. Plateau G' and phase angle (Don et al 2003a) were recorded after preliminary strain sweeps to determine the linear range of these parameters versus strain.

Statistical analyses were performed using Statgraphics Plus 5.0 (Statistical Graphics Group, Warrenton VA). Each determination was made in triplicate. When repeated measures within replicates

TABLE I
Analytical and Farinograph Properties of Four Straight-Grade Flours

Sample	Class	Flour Ash (%) (14% mb)	Flour Moisture (%)	Flour Protein (%) (14% mb)	Farinograph Water Absorption (%)	Farinograph Peak Time (min)	Farinograph Stability Time (min)
Stephens	SWW	0.46	12.8	11.4	54.3	2.2	2.1
Rampart	HRW	0.41	14.1	11.8	58.6	18.7	37.5
Carter	HRW	0.42	14.3	11.8	61.1	31.7	47.9
Bynum	HRW	0.42	14.1	14.2	61.5	9.3	16.4

TABLE II
Mixograph Dough Properties of Flour and Water and Saline (2% w/v aqueous NaCl) Doughs[a]

	Absorption (%)[b]	Peak Time (min)	Bandwith at Peak (mm)	Bandwith 5 min After Peak (mm)	Bandwith 5 min After Peak as % of Bandwith at Peak (%)	Descent Angle (°)
Water						
Stephens	58.0	2.4a	34.5a	10.0a	29.0a	138a
Rampart	63.0	4.3b	40.0b	20.5b	51.3b	152b
Carter	63.5	5.5b	40.0b	10.0a	51.3b	151b
Bynum	76.0	4.0b	37.0a	10.0a	27.0a	144a
Saline						
Stephens	60.0	2.4a	35.0a	9.5a	27.1a	141a
Rampart	65.0	5.6b	56.0b	23.0b	63.9b	174c
Carter	65.0	6.5b	38.0a	22.0b	58.3b	156b
Bynum	69.0	5.3b	34.5a	10.0a	29.0a	133a

[a] Values followed by the same letter in the same column are not significantly different ($P > 0.05$).
[b] Absorption as determined by an experienced dough handler; no statistical calculation was performed.

were taken, averages of the repeated measures were used as representative values for the true replicates. Three-way multifactor ANOVA were run to determine the significance of each main effect and of possible two- and three-way interactions.

RESULTS AND DISCUSSION

Mixograph

Dough characteristics of the four cultivars as assessed by standard mixographs were consistent with farinograph dough mixing data provided by the WWQL. Rampart and Carter both showed longer mix times and better tolerance to overmixing (Tables I and II, Fig. 1). Mixographs with 2% (w/v) saline solution resulted in marginal increases in dough development time and mixing tolerance for the three hard wheats. Mixing time and tolerance for Stephens were unchanged.

Mixographs done in alkali were radically different from the water and saline mixographs (Fig. 1). Numerical data for the alkaline mixograms are not presented as the alkaline mixograms defied standard analyses. The clear differences in mixing characteristics between cultivars seen in water and saline solution were greatly masked. For the three stronger mixing hard wheats, there was no clearly evident peak in the alkaline mixograms, and bandwidth remained at >80% of maximum for the full duration of mixing. Stephens showed a hint of a peak in the mixing curve at ≈2 min and some reduction in bandwidth. However, Stephens bandwidth remained at >60% of maximum for the full duration of mixing with no further reduction of bandwidth even after 30 min of mixing. In contrast, mixograph bandwidth 5 min after peak for the saline doughs derived from the hard wheat samples was <63% of bandwidth at peak and <30% of bandwidth at peak for Stephens (Fig. 1, Table II). Visual and tactile observation showed the alkaline doughs from all cultivars appeared to be grossly undermixed, even after the extended 30 min of mixing. In contrast, after 10–12 min of mixing the flour and water and salted doughs were both extremely sticky and extensible, as expected for overmixed doughs.

Lubricated Squeezing Flow (LSF) on Noodle Doughs

Multifactor ANOVA (Table III) showed that, in general, the main effects had the largest influence on noodle dough LSF attributes. The indicators of dough consistency (ABEV and maximum force) were most affected by cultivar and the salt and alkali treatments. The indicators of dough elasticity (thickness [Ross and Ohm 2006], residual force, %RF, and relaxation time) were much more influenced by resting time. Relaxation time and %RF both measure different aspects of material elasticity. Viscoelastic materials that are primarily elastic in nature will have less stress dissipation when held at constant strain and so will have longer relaxation times (time for stress to decay to a predetermined level) and higher proportional residual stress (%RF). At the extremes, a completely viscous material will have 0% RF and 0 sec relaxation time (stress is relaxed immediately deformation ceases). A completely elastic material will have 100% RF and a relaxation time of effectively ∞, (i.e., longer than the observation period of interest). Steffe (1996 [page 299]) provides a lucid explanation of stress relaxation phenomena in viscoelastic materials. The rest time × salt/alkali interaction term for %RF, and for the cultivar × rest time interaction term for relaxation time were significant and substantial. Figures 2 and 3 show how %RF and relaxation time varied when viewed according to cultivar.

Comparison of Salted and Alkaline Doughs

Overall, alkaline doughs were significantly thicker and had significantly higher LSF biaxial viscosity (ABEV) and maximum force values than salted doughs (i.e., had a harder consistency)

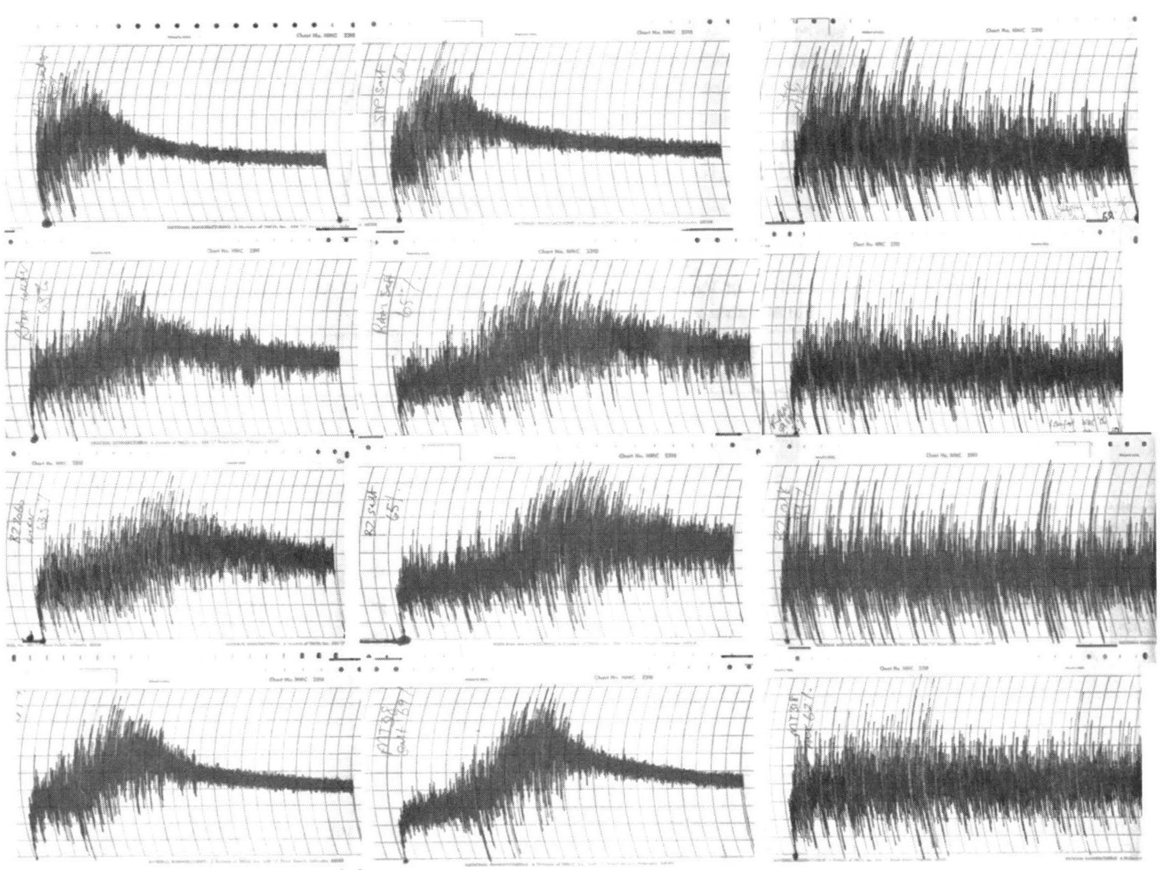

Fig. 1. Representative mixograms. Columns left to right: water; 2% w/v aqueous NaCl; and 1.67% w/v aqueous Na_2CO_3. Rows top to bottom: cultivars Stephens, Rampart, Carter, Bynum.

(Table III). This suggested that, at the constant water addition used, alkaline doughs had greater absorption capacity, leading to harder consistency and higher viscosity. Alkaline doughs also had higher residual force, %RF, and relaxation time values; i.e., they were more elastic than salted noodle doughs. However, the differences between salted and alkaline noodle doughs were not nearly as profound as the differences observed betwen the salted and alkaline mixograms (Fig. 1). To emphasize this point, the hand-feel characteristics of the noodle doughs as observed during processing were not especially different when comparing the salted and alkaline variants. LSF rheology agreed, indicating only small but significant, differentiations between the properties of the salted and the alkaline noodle doughs. In our opinion, this reflected the actual condition of the doughs rather than any insensitivity of the LSF method. The crucial difference seems to be associated with the low water addition in the noodle doughs (32% water addition) compared to the much larger water addition in the mixograph doughs (≈60% water addition). When observing the %RF data subdivided by treatments within cultivars (Fig. 2), it is evident that the differences between salt and alkali were emphasized after the dough resting period. For example, for Carter and Bynum, the alkaline doughs at 0 hr were less elastic (lower %RF). However, after the 24 hr rest times, the alkaline doughs for these two cultivars had higher %RF values than their salted equivalents despite the expected overall decrease in dough elasticity associated with dough resting in both variants. A similar response can be seen for relaxation time (Fig. 3), although the interpretation is not as clear cut.

Comparison Between Cultivars

There were no significant differences in dough thickness related to cultivar (Table III) although, in general, the ranking within cultivars of the individual treatments was similar. For example, the thinnest dough was always the salted dough rested 24 hr for each cultivar (data not shown). Rampart noodle doughs had the highest ABEV, maximum force, and raw residual force values (Table III). As the doughs were made at a constant water addition, it is not surprising that maximum force and ABEV were lower for Bynum noodle dough because at the higher flour protein content, the dough would be expected to be wetter than optimum as higher protein flours have lower optimal water addition for noodle doughs (Park and Baik 2002; Ohm et al 2008) and therefore their noodle doughs should have a softer consistency at constant water addition. This was reflected correctly by the lower ABEV and maximum force values (Ross and Ohm 2006). The three hard-grained cultivars were effectively indistinguishable for the elasticity-related parameters of %RF and relaxation time, and their noodle doughs were all significantly more elastic, as indicated by these parameters, than the noodle dough of the soft-grained cultivar Stephens (Table III). The %RF and relaxation time values of the three hard-grained cultivars were aligned with their mixograph mixing times but did not reflect the significantly lower mixing tolerance of dough derived from cultivar Bynum (Fig. 1, Table II).

Comparison of 0 hr (Unrested) and 24 hr (Rested) Doughs

Unrested (0 hr) noodle doughs were significantly thicker, had lower ABEV, lower maximum force, and higher residual force, %RF, and relaxation times (Table III). The higher elasticity compared to the rested doughs (i.e., higher %RF and relaxation times) was consistent with our understanding of the stressed state of the unrested doughs. However, the consistently lower maximum force and ABEV values in the unrested doughs are a conundrum. If our previous interpretation was correct, that a softer consistency was reflected by lower ABEV and maximum force values, then the unrested doughs appeared to be softer in consistency than the rested doughs, even though they were determined to be more elastic.

Glutenin Macropolymer Observations

GMP isolated from Stephens flour exhibited different textural and visual characteristics compared to GMP isolated from flour of the three hard wheats. GMP isolated from Stephens flour appeared to be clear and watery and flowed easily. In contrast, GMP isolated from the three hard wheat flours was less clear and exhibited less apparent flow. The physical observations were confirmed by rheological testing. For all four cultivars, GMP gels isolated from the dough-compounding stage onwards were gummier in texture and more opaque. Generally, the gummier texture was less prominent in GMP isolated from the salted noodle doughs after they were rested for 24 h. In contrast with the clear to white appearance of the salted GMP gels, GMP gels isolated from the

TABLE III
***F*-Values and Mean Values from Analysis of Variance of Lubricated Squeezing Flow (LSF) Attributes of Noodle Doughs Formulated with Either Salt or Sodium Carbonate[a,b]**

F-Ratios	Dough Thickness (mm)	Apparent Biaxial Extensional Viscosity (kPa.s)	Maximum Force (N)	Residual Force (N)	% Residual Force	Relaxation Time (sec)
Main effects						
Cultivar	1.37ns	56.47***	46.96***	125.22***	393.3***	123.49***
Rest time	88.36***	27.47***	8.16**	1283.7***	5825.1***	1935.0***
Salt/alkali	24.84***	154.98***	133.50***	261.33***	121.5***	9.86**
Interactions						
Cultivar × rest time	1.54ns	5.51**	8.47***	9.83***	12.9***	74.1***
Cultivar × salt/alkali	2.83ns	6.53**	7.53***	9.61***	3.3*	0.83ns
Rest time × salt/alkali	6.90*	2.08ns	0.45ns	10.41**	115.2***	2.63ns
Cultivar × rest time × salt/alkali	ns	ns	ns	ns	4.8**	3.17*
Main effect means						
Stephens	2.25a	1,854c	113.7c	23.0a	20.4a	5.8a
Rampart	2.27a	1,981d	122.4d	32.9d	27.0b	10.7b
Carter	2.25a	1,710b	106.5a	28.8c	27.0b	11.7c
Bynum	2.17a	1,541a	100.6a	27.2b	26.9b	11.1bc
Rest time						
0 hr	2.41b	1,706a	108.8a	34.5b	31.7b	15.3b
24 hr	2.06a	1,837b	112.7b	21.5a	19.0a	4.4a
Salt/alkali						
Alkali	2.33b	1,927b	118.6b	30.9b	26.2b	10.2b
Salt	2.14a	1,616a	103.0a	25.1a	24.4a	9.5a

[a] *, **, and *** significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively; ns, not significant.
[b] Values followed by the same letter in the same column and section are not significantly different ($P > 0.05$).

alkaline doughs were light yellow in color, suggesting that the addition of alkali may have caused pigments to be co-extracted with the GMP. GMP gels isolated from the alkaline dough compounding stage onwards were again more opaque and gummier in texture than GMP gel isolated after the mixing stage. The overall increase in gumminess from the compounding stage onward was more profound in the alkaline GMP gels. Alkaline GMP gels also felt stickier and exhibited less apparent flow compared to the analogous GMP gels isolated from salted noodle doughs.

GMP weight. Multifactor ANOVA (Table IV) showed that all three main effects significantly influenced the wet weight of GMP extracted from flour and at the selected noodle dough processing stages. The significant interaction term for processing stage × salt/alkali reflects a real difference in the response of the GMP weight to processing across the salted and alkaline variants. Overall, the salted doughs gave a slightly but significantly higher GMP yield. The lower GMP yield from Stephens is consistent with its lower dough strength characteristics. Overall, the wet weight of GMP extracted from the different processing stages showed consistency with previous observations made on conventional doughs. However, the extent of the reduction was not as great and was intermediate between the almost total loss of GMP seen in conventional doughs (Don et al 2003a) and the maintenance of GMP weight when dough was mixed in simple shear (Peighambardoust et al 2005). The GMP weight minimum was reached at the end of the compounding stage with no further significant decrease through the reduction sheeting process. GMP weight increased upon subsequent dough resting and thus is consistent with previous observations with conventional breadmaking doughs (Weegels et al 1997). However, the main effect means for processing stage mask profound differences occurring in loss and recovery of GMP weight when comparing salted and alkaline doughs across the process. Figure 4 shows the data presented to isolate the processing stage × salt/alkali interaction. Under this analysis, each cultivar reacted differently in the alkaline variant. Stephens GMP weight (Fig. 4A) was slightly but significantly lower in the alkaline variant across most processing stages. For Rampart and Carter (Fig. 4B and C), GMP weight decreased more slowly but it decreased more in the alkaline variant during the active phase; the increase in GMP weight after resting was significantly lower than that observed after resting in the salted variant. For Bynum (Fig. 4D), GMP weight in the alkaline variant was not significantly different or even slightly higher than in the salted variant during the active phase. But, in this case, GMP weight did not increase at all after resting and was therefore much lower than the GMP weight from the rested salted Bynum dough. The only correspondence to conventional dough testing that can be seen here, if one is imaginative, is that the two cultivars that had any substantial increase in GMP after resting in the alkaline variant were the two cultivars with the better mixing tolerance in mixograph and farinograph testing (Tables I and II).

GMP rheology. Multifactor ANOVA (Table IV) showed that all three main effects significantly influenced GMP gel strength (expressed as GMP gel G'). Stephens flour, as expected not only had less GMP, it had substantially and significantly lower GMP gel strength, reflecting its weak dough attributes. Overall, GMP gel strength increased from flour through mixing and compounding and it showed no further change after sheeting. GMP subsequently extracted from the rested doughs was not significantly different in gel strength compared to the latter stages of the active phase. This result masks the profound differences in GMP gel strength across the salted an alkaline variants that occurred after resting, signified by the significant interaction terms for cultivar × processing stage and processing stage × salt/alkali (highlighted in Fig. 5). For example, GMP gel G' in cultivar Stephens (Fig. 5A) remained constant across the process in the salted variant but substantially increased in the alkaline variant. In the hard wheats and the alkaline Stephens dough, GMP gel strength generally increased during the active phase of processing, reaching a maximum either after the compounding or sheeting stages. However, the most striking difference was observed for GMP extracted after dough resting. In this case, gel strength from GMP extracted from alkaline dough again increased for all cultivars except Carter, where it remained constant. This was in direct contrast to the decrease in GMP gel strength between the end of the active phase and the resting time for all three hard wheat salted doughs. The increased GMP gel G' in the alkaline doughs was consistent with the handfeel characteristics of the gels noted above. The increases in GMP gel G' observed in both formulation variants across the active phase of processing is also in stark contrast to earlier findings from conventional doughs. Don et al (2003) showed that for different optimum mixing times in three cultivars, the GMP gel

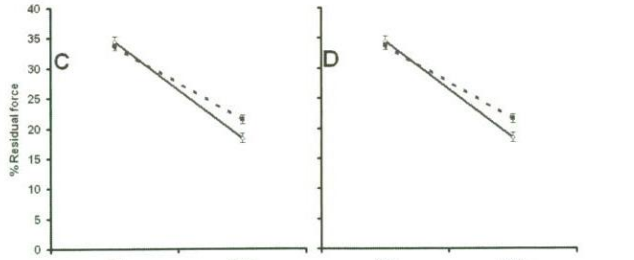

Fig. 2. Residual force as a percentage of maximum force plotted against dough rest time. Stephens (**A**); Rampart (**B**); Carter (**C**); Bynum (**D**). Solid lines with open symbols: salted doughs. Dotted line with closed symbols: alkaline doughs. Error bars represent ± 1 LSD (0.76%) between alkaline and salted treatments at $P = 0.05$.

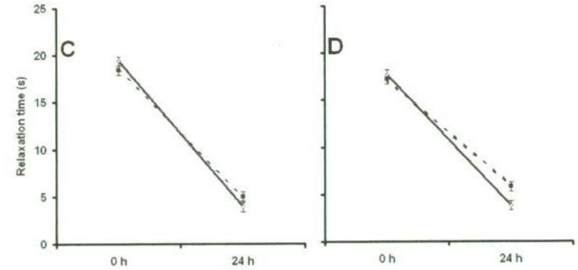

Fig. 3. Relaxation time plotted against dough rest time. Stephens (**A**); Rampart (**B**); Carter (**C**); Bynum (**D**). Solid lines with open symbols: salted doughs. Dotted line with closed symbols: alkaline doughs. Error bars represent ± 1 LSD (0.5 sec) between alkaline and salted treatments at $P = 0.05$.

strength decreased almost linearly as mixing proceeded. It appears that alkali increased the strength of the extracted GMP gels, but the mechanism by which this occurred is as yet unknown.

CONCLUSIONS

Mixograph dough properties of the four cultivars were assessed in conventional flour and water doughs. These properties were consistent with those observed using a farinograph (Table I) and also with saline mixograph properties (Table II, Fig. 1). The dilute saline solution increased mixograph mix time for the three hard wheat samples but did not alter the distinctions between the four cultivars. Using a dilute Na_2CO_3 solution resulted in radically different mixograms. Differences between cultivars were masked and alkaline-carbonate doughs appeared to be grossly undermixed even after extensive (>30 min) mixing.

Low-water sheeted noodle doughs did not exhibit the gross differences between the salted and alkaline variants seen in the high-water mixograph doughs. This was evident both from dough handling assessments and from LSF testing. Although differences were subtle. they were statistically significant and systematic (Table III). Alkaline doughs had harder consistency and were more elastic. Higher elasticity was most evident after 24 hr of resting, even though the overall elasticity for both variants, as expected, dropped markedly over this period (Table III, Figs. 2 and 3). LSF showed differences between cultivars consistent to some degree with their properties when tested at conventional water additions in water or saline solution, reflecting more the mix times than the relative tolerances to overmixing (Tables II and III).

GMP extracted from noodle doughs of both the salted and alkaline variants showed the expected decrease in GMP weight across the active phase of processing. This was consistent with previous observations of conventional doughs (Don et al 2003a). However, this decrease was not as great as at full development in conventional doughs where GMP weight declined to almost zero (Don et al 2003a). The decrease was intermediate between that observed in conventional dough mixing and mixing in simple shear (Peighambardoust et al 2005). But we were unable to determine whether this was a function of some similarity between sheeting and simple shear or whether the noodle doughs were simply not fully developed. Overall, GMP weight was lower in alkaline doughs. After resting, the GMP weight increased again in salted doughs, as expected from previous observations (Weegels et al 1997). However, in a departure from previous observations, GMP weight from the alkaline doughs either failed to increase after resting or increased to a lesser extent than for the salted variants (Fig. 4). These results suggest a general propensity for more GMP depolymerization during active processing and less repolymerization on resting in the alkaline doughs.

GMP rheology was also affected by cultivar, formulation, and resting, but there were significant statistical and practical interactions between the treatments (Table IV). In a substantial departure from previous observations of GMP gel strength, which decreased as mixing progressed in conventional doughs (Don et al 2003a), GMP gel strength increased or at least remained constant during the active phase of noodle dough processing (Fig. 5). The interaction was most evident after resting. In the salted doughs, GMP gel strength decreased after resting, with the single exception of the GMP from Stephens. In the alkaline doughs, in all but one case, GMP gel strength significantly increased after resting the doughs for 24 hr. In the exceptional case, GMP gel strength remained constant but did not decline, as was observed in GMP from salted doughs. This is consistent with the LSF results that show that over the rest period the alkaline doughs did not relax as much (described best by %RF) (Fig. 2). Overall, this indicated some profound differences in the glutenin fraction in low-water doughs as compared to conventional doughs. Further work is being conducted to characterize the GMP from both types of noodle doughs

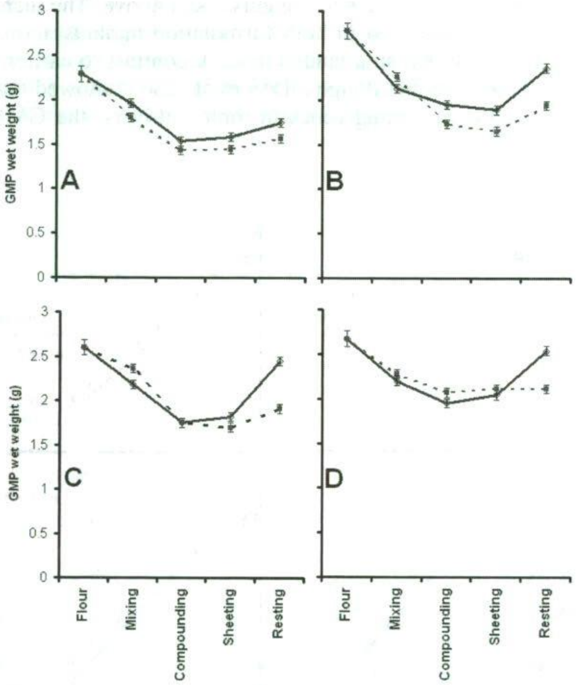

Fig. 4. Glutenin macropolymer wet weight plotted against dough processing stage. Stephens (**A**); Rampart (**B**); Carter (**C**); Bynum (**D**). Solid lines with open symbols: salted doughs. Dotted line with closed symbols: alkaline doughs. Error bars on dough processing stage data points represent ± 1 LSD (0.05 g) between alkaline and salted treatments at $P = 0.05$. Error bars on flour data points represent ± 1 LSD (0.09 g) between processing stages at $P = 0.05$.

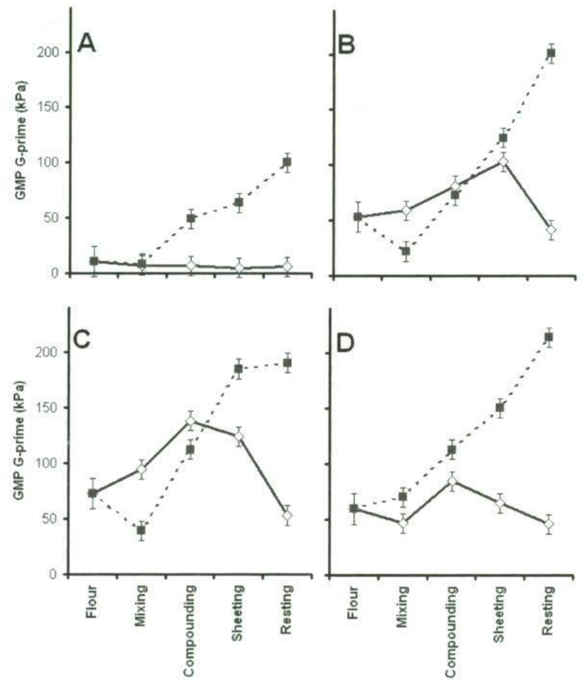

Fig. 5. Glutenin macropolymer gel strength (G') plotted against dough processing stage. Stephens (**A**); Rampart (**B**); Carter (**C**); Bynum (**D**). Solid lines with open symbols: salted doughs. Dotted line with closed symbols: alkaline doughs. Error bars on dough processing stage data points represent ± 1 LSD (8.8 kPa) between alkaline and salted treatments at $P = 0.05$. Error bars on flour data points represent ± 1 LSD (13.7 kPa) between processing stages at $P = 0.05$.

TABLE IV

***F*-Values and Mean Values from Analysis of Variance of Wet Weight and Gel Strength of Glutenin Macropolymer (GMP) Extracted from Noodle Doughs Formulated with Salt or Sodium Carbonate**[a,b]

F-Ratios	GMP Wet Weight	GMP Gel G'
Main effects		
Cultivar	62.6***	56.8***
Processing stage	120.9***	32.0***
Salt/alkali	13.2***	69.7***
Interactions		
Cultivar × processing stage	2.2*	1.7ns
Cultivar × salt/alkali	0.8ns	3.6*
Processing stage × salt/alkali	8.2***	38.8***
Cultivar × processing stage × salt/alkali	ns	ns
Main effect means		
Cultivar		
Stephens	1.76a	25.7a
Rampart	2.15b	81.2b
Carter	2.11b	108.2c
Bynum	2.26c	90.9b
Processing stage		
Flour	2.58c	49.0a
Mixing	2.15b	43.3a
Compounding	1.77a	82.2b
Sheeting	1.78a	102.6c
Resting	2.08b	105.2c
Salt/alkali		
Alkaline	2.02a	95.6b
Salt	2.12b	57.3a

[a] *, **, and *** significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively; ns, not significant.

[b] Values followed by the same letter in the same column and section are not significantly different ($P > 0.05$).

and to see whether these results might lend themselves to practical application in selecting wheats with enhanced properties for alkaline noodle making.

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